COMPUTER - AIDED STOCK LAYOUT FOR BLANKING

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CERTIFICATE

This is to certify that the work entitled "Computer-Aided Stock Layout for Blanking" has been carried out by Shri Subbarayudu, K.V., under my supervision and has not been submitted elsewhere for the award of a degree.

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LIST OF SYMBOLS

A	-	Area of blank in mm^2
B	-	Bridge width in mm
C	-	Longest of maximum horizontal distances in mm
D	-	Increment of shifting in mm
e	-	y-intercept of a straight line
F	-	Function defined by $F(y) = 2 \times \text{constant} - y$
G	-	Shortest of minimum horizontal distances in mm
H	-	Blank width in mm
k	-	Constant defining horizontal mirror line
L	-	Maximum horizontal length in mm
m	-	Slope of a straight line
N	-	Number of vertices
P	-	Pitch in mm
r	-	Number of points of intersection
S	-	Sheet width in mm
t	-	Thickness of sheet stock in mm
U	-	Area utilization (ratio)
U_o	-	Overall area utilization (ratio)
V	-	Minimum vertical distance between blanks in mm
W	-	Stock width in mm
$\bar{x}$, $\bar{y}$	-	Coordinates of centroid of blank
x, y	-	Initial coordinates of blank
x1, y1	-	Coordinates of Blank-I
x2, y2	-	Coordinates of Blank-II
y_m	-	Average of y coordinates of top and bottom most points on Blank-I in a orientation
$\forall$	-	For all.

ABSTRACT

Substantial savings in material cost can be achieved by reducing the scrap to a minimum in blanking operation. Stock layout for blanking determines amount of scrap. Stock layout has been traditionally a manual operation which is time-consuming. The solution is highly dependent on skill and experience of a designer. The present work is an effort to computerize stock layout for blanking.

Four types of stock layout solutions sought by computer-aided methods are:

(1) single row uniform orientation (SIRUO) layout

(2) single row half-turn (SIRHT) layout

(3) double row half-turn (DORHT) layout and

(4) double row mirror image (DORMI) layout,

Strategies adopted for obtaining these layouts are explained.

The stock layout problem is treated considering the design requirement of maximizing strength of parts when subsequent bending is involved, and width of sheet available.

Radhakrishnan[4] proposed algorithms for SIRUO and SIRHT layouts of polygon shaped blanks (PSB) and for SIRUO layout of blanks with arc segments. These algorithms are corrected, and reported in Appendix A. As an extension to his work, algorithms are proposed for double row — DORHT and DORMI — layouts of PSB. Cnee's heuristic search is performed to get improved solution and reduce computation time.

The algorithms are coded in FORTRAN 77 with PLOT-10 IGL graphics package.

The algorithms for four strategies of layout of PSB are integrated and implemented as an interactive program. The algorithms are tested for typical examples and the results are reported.

The algorithm for SIRUO layout of blanks with arc segments is also tested for typical examples and the results are reported.

The programs provide the designer a guideline to select an appropriate layout from the layout solutions and also generate manufacturing information such as stock width, pitch, area utilization etc.

CHAPTER I

INTRODUCTION AND LITERATURE SURVEY

1.1 Introduction:

Most of the operations for manufacturing parts from sheet metal are classified into cutting, forming, and drawing operations. Production of sheet metal components involves any one or a combination of operations such as blanking, punching, piercing, bending, drawing etc.

Blanking is a cutting operation in which the cutting is done along an enclosed contour. Blanking is a primary operation which may produce a finished component or it may be a forerunner for subsequent operations. Blanking is required for production of a wide range of components e.g., sewing machine parts, keys, levers, rocker arms, washers, transformer stampings (laminations), blanks for subsequent drawing etc.

If blanks are produced by laying out lengthwise or crosswise from sheet-stock, it would result in a great wastage of material. In such cases, it is possible to arrange blanks in other orientations and positions on sheet-stock resulting in reduction of scrap.

In medium and high production of medium-size blanks, the cost of material is 50% to 75% of the total cost of the blank [1]. For large blanks, it is more than 95% of the total cost of the blank. Substantial savings in net material cost can be achieved by "reducing the scrap to a minimum".

The traditional method of achieving a satisfactory stock layout is by arranging the cardboard templates in different orientations and positions. The method is essentially a trial and error one, and hence time-consuming. The solution is highly dependent on skill and experience of the designer.

1.2 Literature Survey:

Stock layout refers to arrangement of blanks on sheet-stock. Stock layout is generally classified as (1) single shape layout and (2) multiple shape layout. Stock layout for blanking is a single shape layout problem.

Chow [2] suggested three approaches to single shape problem: (i) Scrap-free design, (ii) Bounding parallel lines method, and (iii) Computation algorithms.

(i) Scrap-free design implies that the boundary of a blank must be made up of congruent lines to generate interlocking blanks. A skillful designer makes a compromise between functional and symmetrical features to improve nesting.

(ii) Bounding parallel lines method determines a minimum area parallelogram that encloses a given convex blank and results in an optimum arrangement in single row.

(iii) Computation algorithms method involves nesting of any given blank in a specified pattern. Three computation algorithms for single, and double row arrangements were given by Chow [2]. The double row arrangement includes a half-turn or a minor reflection. The solution was

arrived at by rotating the blank from 0° (initial orientation) to 180° and comparing area utilization for every orientation.

Cnee [3] gave a blank layout solution for polygon shaped blanks (PSB). The solution was also arrived at by testing different orientations from 0° (initial orientation) to 180°. An extended heuristic search was further performed to improve the solution. The solution involved single row and pairwise layouts. Sheet width constraint was taken into account. He also compared alternative layouts considering die costs.

Radhakrishna [4] developed programs for strip-layout and blanking-die design for PSB. He considered single row and pairwise layouts for strip layout. He also tried to develop an algorithm for single row layout of blanks with arc segments.

Nakagawa and Yokoi [5] dealt with optimization of planning of sheet shearing and coil slitting for blanking to minimize scrap percentage for small batch production of different blank dimensions.

Shibata and Kunitomo [6] described a sheet metal CAD/CAM system. This system is an interactive graphical processing system to design sheet metal products and generate manufacturing information. In this system, the problem of nesting of single shape is integrated with other functions of the system.

1.3 Scope of Present Work:

It is intended to study and test, the algorithms proposed and the programs developed for various layouts by

Radhakrishna [4]. As an extension to his work, it is intended to develop algorithms for double row — half-turn and mirror reflection — layouts of PSB. It is intended to integrate, and test the various algorithms and develop a user-friendly interactive program to get various solution layouts of a blank on a given sheet-stock of standard width.

CHAPTER II

STOCK LAYOUT FOR BLANKING

2.1 Introduction:

Problem of stock layout for blanking is delineated in the present chapter. Section 2.2 describes the terminology used in stock-layout design for blanking. Section 2.3 describes factors governing stock layout. The proposed classification of stock layout is described in Section 2.4. The various approaches to stock layout problem adopted in the literature are classified and described in Section 2.5. Subsection 2.5.1 describes strategies adopted in the present work to obtain specific types of layout solutions.

2.2 Terminology for Layout Design:

The terminology used to describe stock layout is illustrated in Figure 1.

Pitch P: Distance along stock length between corresponding points of two successive blanks in the same orientation in a row.

Bridge Width B: Required minimum distance between two adjacent blanks, or blank and adjacent edge of the stock.*

Blank Width H: Width of a blank, as laid out on sheet-stock, normal to stock length.

Stock Width W: Minimum width of sheet-stock, including bridge widths, required to produce blanks as laid out in stock layout in one or more rows.

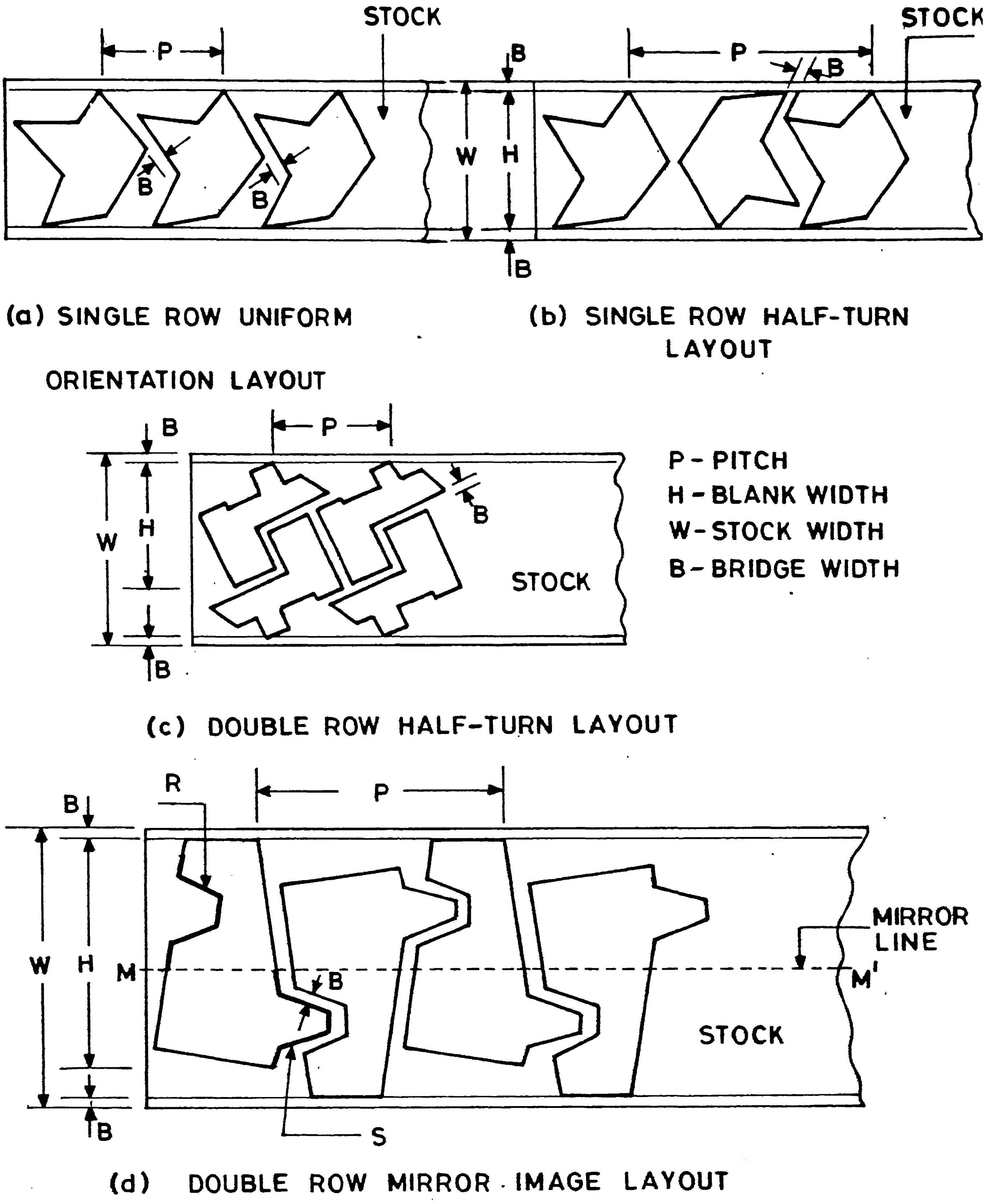


FIG. 1 TYPES AND TERMINOLOGY OF STOCK LAYOUT FOR BLANKING.

Sheet Width S: It is the width of standard sized sheets which are slit into stocks of suitable width.

Area Utilization U: Ratio of blank area A to area of sheet-stock consumed for producing one blank.

$$U \text{ (percentage)} = \frac{n \times A}{PW} \times 100$$

where n is the number of blanks laid out on stock of width W and pitch P.

Overall Area Utilization U_o: Ratio of blank area to area of sheet consumed for producing one blank.

$$U_o = \frac{WM}{S} \times U$$

where M is the number of sheet-stocks of width W that can be slit from the sheet of width S.

2.3 Factors Affecting Stock Layout:

Various factors that govern stock layout are explained below [7]:

1. Percentage Area Utilization or Yield: It is a major consideration in determining stock layout. Scrap is the complement of utilization. The layout determines the amount of scrap. Provision of required bridge width reduces utilization. But the provision is mandatory to avoid slipping of sheet material along the cutting edges of punch and die. The layout also determines the amount of side losses that occur while slitting the sheet of standard width to suitable widths of stock. Overall area utilization takes the side losses also into account.

2. Type of Stock: The stock may be in the form of strip or coil. Strip stock can be passed through the die more than once, whereas coiled stock is passed through the die only once. Stock layout should satisfy the restriction in number of passes through die.

3. Direction of Fiber: When subsequent bending of blank is involved, fiber direction affects stock layout. Bends are recommended to be made at an angle of 90° to the fiber direction. This requirement either fixes the orientation of blank or restricts the orientations to a limited range.

4. Direction of Burr: If the burr is on hidden surface, it does not always have to be removed. The stock layout which gives burr on same side of all blanks is preferred.

5. Press Used: Press tonnage and bed area limit stock layout. Balancing of forces evenly around the centreline of the press ram also affects stock layout.

6. Production Size: Type of stock and die, and number of passes are determined by the production size.

7. Type and Cost of Die: Type of die preferred for given conditions of production influences stock layout. Cost of die should be kept in mind in determining layout.

2.4 Classification of Stock Layout:

Figure 2 shows various stages of a proposed classification of stock layout keeping computational methods of stock layout in view.

Stage-I is based on number of distinct shapes considered for layout. Stage-II is based on nature of geometry of contour

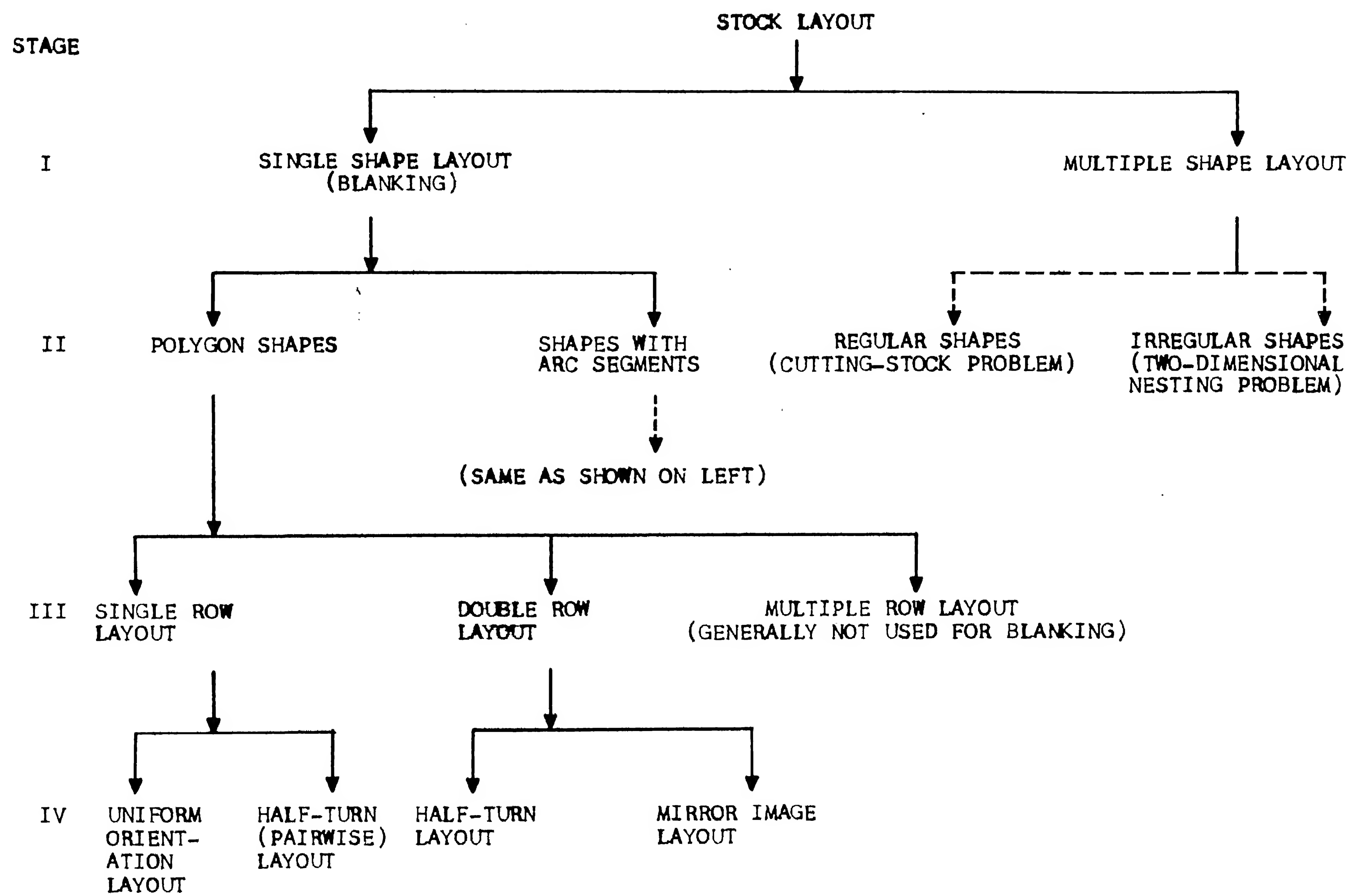


FIG. 2 CLASSIFICATION OF STOCK LAYOUT

of shape. Classification at stage-II emphasizes the differences in computational approaches to the two problems. Stage-III is based on distinctive number of rows of blanks on the sheet-stock. Stage-IV refers to various patterns of arrangement of blanks, generally sought by computational methods.

The various types of layout for polygon shaped blanks (PSB) are shown in Figure 1.

(a) Single Row Uniform Orientation (SIRUO) Layout (Figure 1-a): Blanks are laid out in a single row in stock width and all blanks are in same orientation. Blanks can be produced by a single pass of the stock through the die and punch assembly.

(b) Single Row Half-Turn (SIRHT) Layout (Figure 1-b): Blanks are laid out in a single row and every blank is at half-turn (or 180°) orientation to the preceding one. It is also called "pairwise layout". Blanks can be produced using a single blanking-die. The sheet-stock (strip) is to be turned around (i.e., by half-turn) after first pass and passed through the die again. The layout is generally used due to higher utilization than SIRUO layout. Direction of burr is same for all blanks and better balancing of die cutting forces is achieved.

(c) Double Row Half-Turn (DORHT) Layout (Figure 1-c): Blanks are laid out in two rows such that blanks in one row are at half-turn orientation to the blanks in the other row. Blanks can be produced using a single blanking die in the same way as explained for SIRHT layout. All the advantages for the SIRHT layout are valid in this case also. However, utilization is generally more than that obtained in SIRHT layout.

(d) Double Row Mirror Image (DORMI) Layout (Figure 1-d): Blanks in one row are gliding mirror images of the blanks in other row about a central line (mirror line) parallel to stock length. To produce blanks using a single blanking die, the stock is to be turned upside down after the first pass and passed through the die again. The sheet-stock should have same surface features on both sides. The layout is generally not preferred because direction of burr will not be same for all blanks produced.

2.5 Approaches to Stock Layout Problem:

Figure 3 gives a proposed classification of various approaches to stock layout adopted in the literature considering (a) single shape problem and (b) multiple shape problem.

The various approaches to stock layout for blanking are explained below.

1. Scrap-free Design [2]: It implies designing symmetrical and regular blanks that interlock with one another. This approach at design phase is often not practicable due to drastic modifications required which may alter both function and appearance of blank.

2. Conventional Templates Method: It is a trial and error method using cardboard templates cut to the same profile as the blank. The method is tedious and time-consuming especially for complicated shapes. The solution is highly dependent on skill and experience of the individual.

3. Computer-aided Methods: At present, there are two

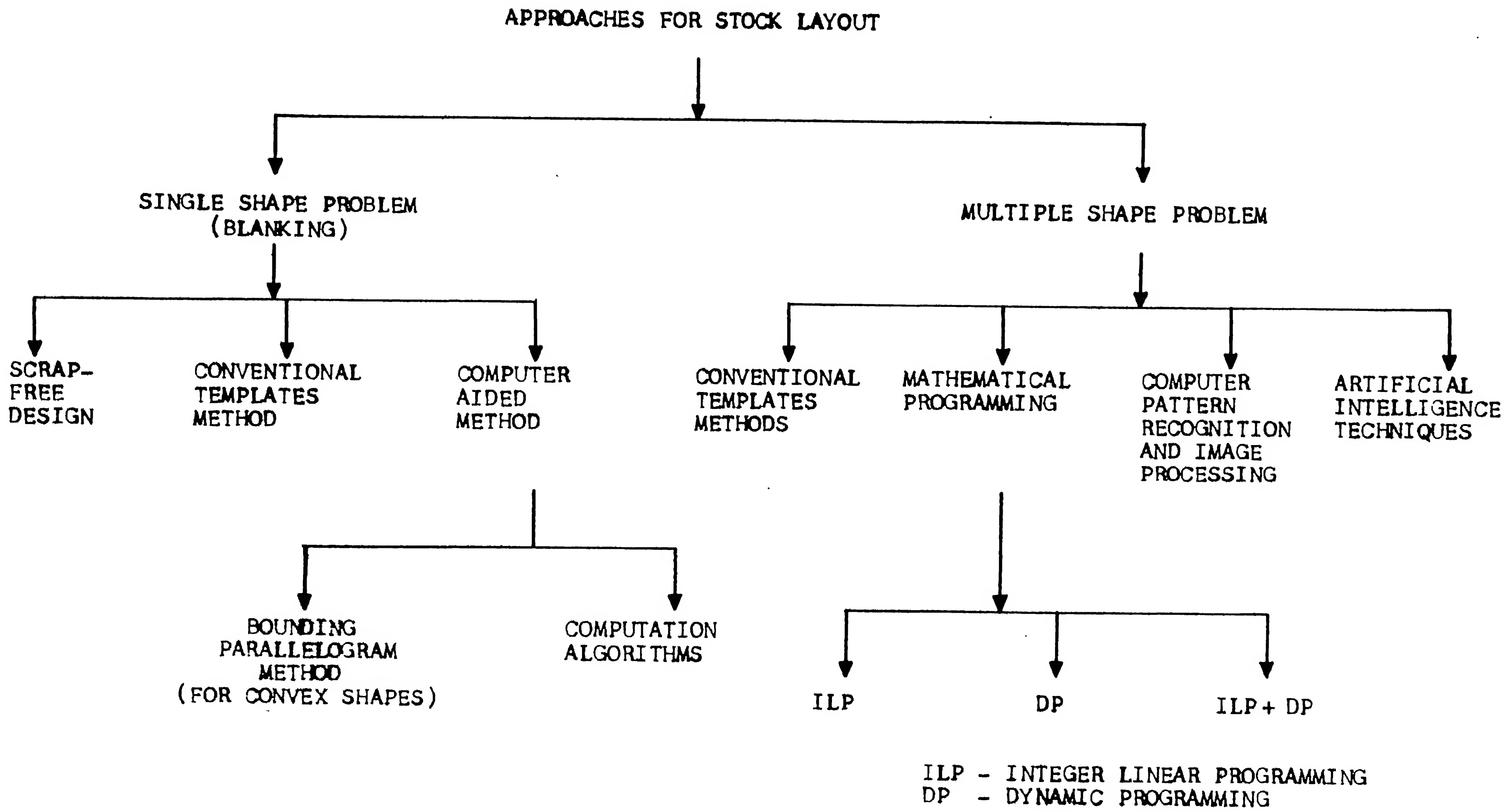


FIG. 3 CLASSIFICATION OF APPROACHES TO STOCK LAYOUT PROBLEM.

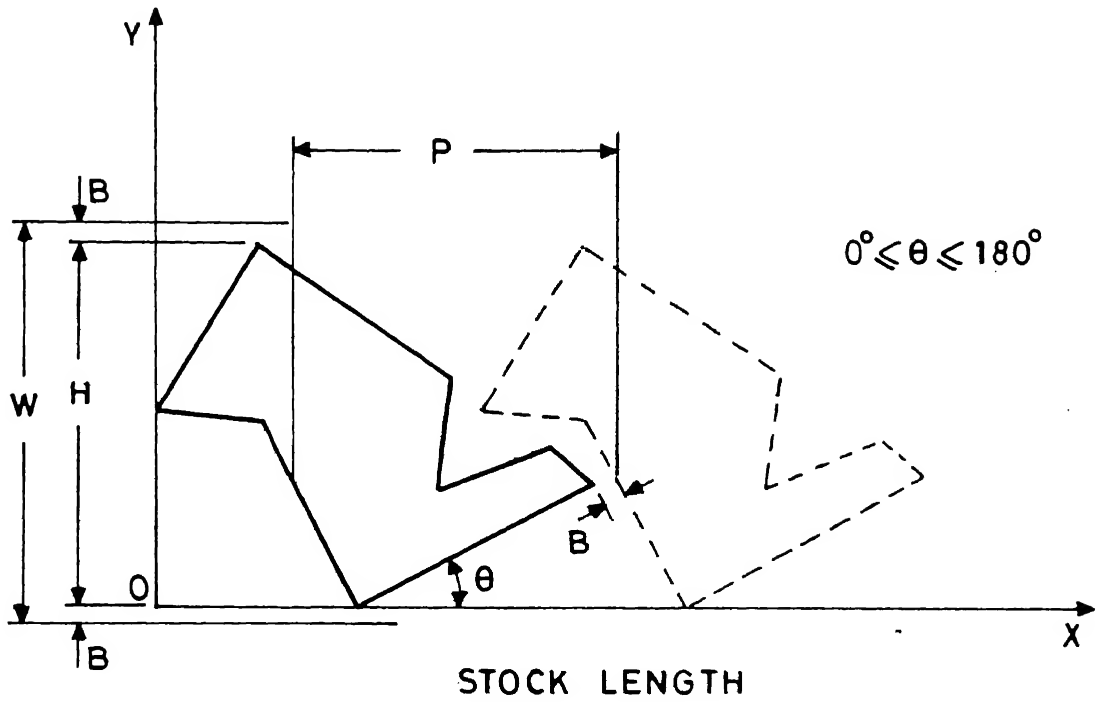
approaches in computer-aided methods. In the first method namely bounding parallel lines method, blank is characterised by two pairs of bounding parallel lines, forming a parallelogram. For a blank to be arranged in SIRUO layout, the problem is equivalent to finding an enclosed parallelogram with a minimum area. It gives reasonably good results for convex shapes only [2]. The second method viz., computation algorithms, can handle a wider range of components. The various strategies of the method are given in Section 2.6.

2.6 Strategies for Stock Layout:

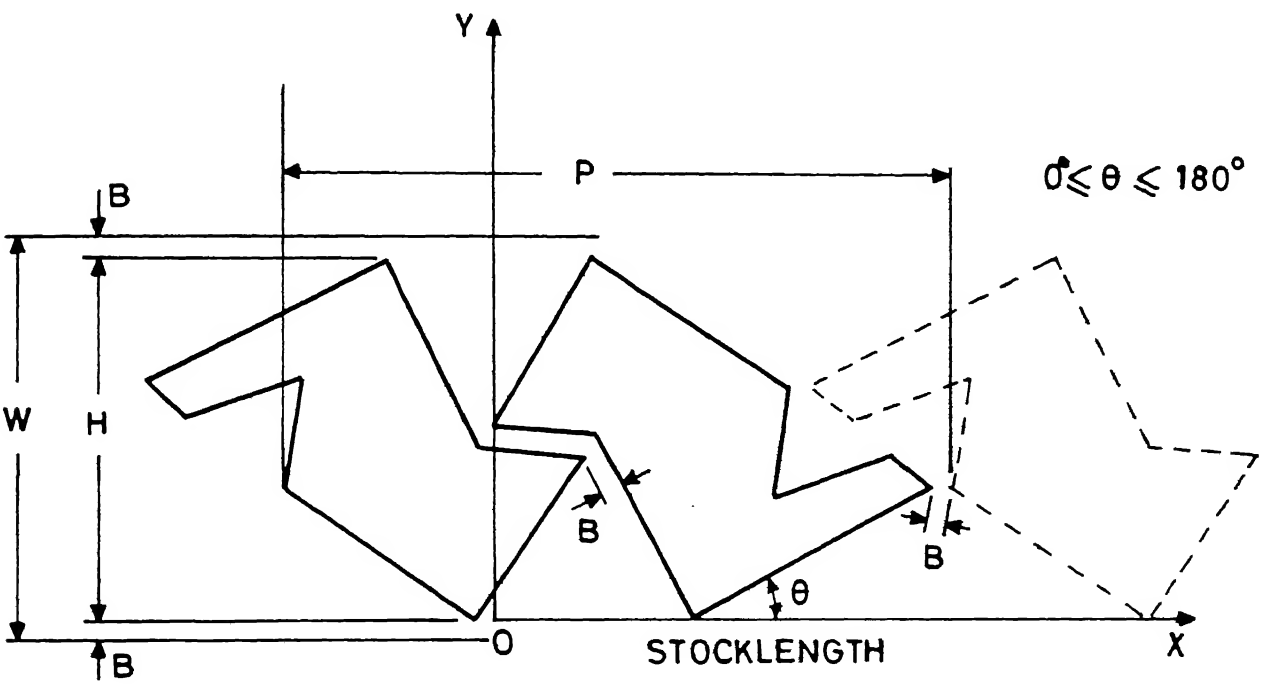
Strategies by computation algorithms method to obtain each of the four types of layouts described in Section 2.4 are briefly explained below.

(a) Single Row Uniform Orientation Layout (Figure 4-a): Blank is rotated in steps from 0° (initial position) to 180°. Width W and pitch P and either area utilization U or overall area utilization U_o are determined for each orientation. Area utilization is determined when sheet width is not specified whereas overall area utilization is taken when sheet width is specified. The orientation which gives maximum utilization (U or U_o) is selected and blanks are arranged in that orientation in a single row at pitch distance.

(b) Single Row Half-Turn Layout (Figure 4-b): In this strategy also, a blank is rotated in steps from 0° (initial position) to 180°. At each orientation, a second blank is placed at half-turn orientation (180° to the orientation being



(a) SINGLE ROW UNIFORM ORIENTATION LAYOUT



(b) SINGLE ROW HALF-TURN LAYOUT SOLUTION

FIG. 4 STRATEGIES FOR SINGLE ROW LAYOUT SOLUTIONS

considered) beside the first blank; consistently either to the left or to the right of the first blank. Area utilization (U or U_o) is calculated for the cluster of two blanks to select layout solution.

(c) Double Row Half-Turn Layout (Figure 6): Blank-I is rotated in steps from 0° to 180°. Blank-I is always kept in the first quadrant. At each orientation of Blank-I, Blank-II is placed in the third quadrant at 180° orientation to Blank-I (Figure 6-a). Blank-II is shifted incrementally (Increment D) in a direction (y-axis) normal to stock length. Shifting of Blank-II is continued till it clears the top of Blank-I (Figure 6-c). At each incremental shift, the blanks are placed side by side by translating one or both the blanks along stock length (x-axis). The layout solution is selected by comparing utilization for all positions corresponding to each incremental shift for each orientation.

(d) Double Row Mirror Image Layout (Figure 8): Blank-I is rotated in steps from 0° to 180°. At each orientation of Blank-I, a mirror line parallel to stock length is selected to pass through the bottom most point of Blank-I. The mirror line is shifted incrementally in a direction (y-axis) normal to stock length from the bottom most point to the top most point of Blank-I. At each position of mirror line, the image about the mirror line i.e. Blank-II is translated in the direction of stock length and placed beside Blank-I. The layout which gives maximum utilization is selected.

In all the above strategies, four cases arise depending upon the direction of bend, if any.

Case I: Either subsequent bending of blank is not involved or its effect is not important. The blank is rotated in steps from 0° to 180° and optimal layout is selected as explained above.

Case II: Subsequent bending of blank is involved and it requires the bend to be normal to the fiber direction. In this case, the orientation of blank gets fixed. For the orientation, area utilization is determined and stock layout is obtained.

Case III: Subsequent bending of blank is involved and it allows a limited range of orientations. Orientations, in steps, within the range are considered for optimal layout.

Case IV: More than one bend direction is to be taken into account,or sheet width happens to limit some of the possible orientations.

CHAPTER III

DOUBLE ROW HALF-TURN LAYOUT FOR POLYGON SHAPED BLANKS

3.1 Introduction:

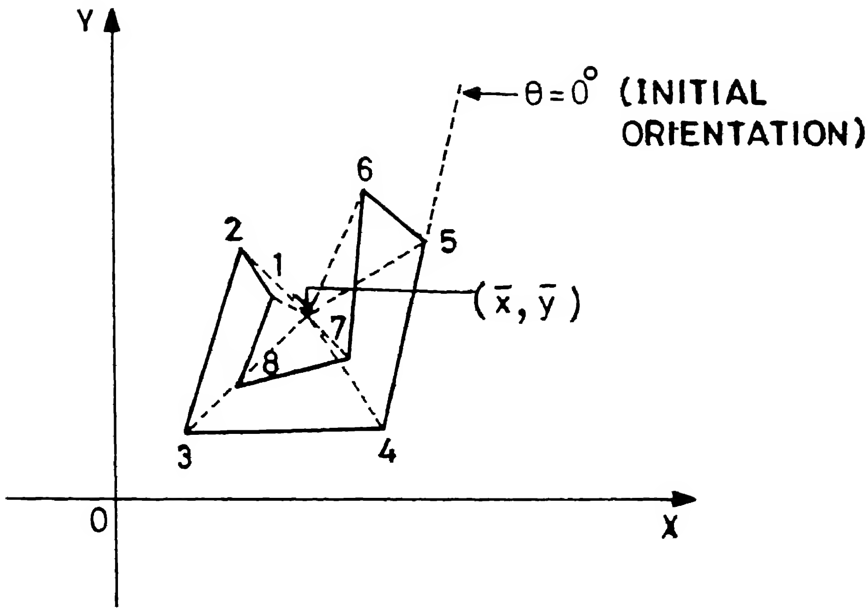
Radhakrishna [4] proposed algorithms for single row uniform orientation (SIRUO) and single row half-turn layouts of polygon shaped blank (PSB). He also proposed algorithms for SIRUO layout of blanks with arc segments. To implement these algorithms, some corrections are made in the algorithms reported in his thesis and these corrections are given in Appendix A. The present chapter describes important steps in algorithms for double row half-turn layout of polygon shaped blanks. Section 3.2 gives blank representation and method of calculation of blank area. Section 3.3 gives representation of blanks in different orientations and positions. Sections 3.4 to 3.6 give procedure for calculation of width, pitch, and area utilization for any orientation and position of blanks.

3.2 Blank Representation and Area Calculation:

Blank is represented as a polygon (Figure 5) which is defined by x and y coordinates of all vertices. Area of the polygon is calculated by determining centroid of area as follows.

$$\bar{x} = \frac{1}{N} \sum_{i=1}^{N} x_i ; \qquad \bar{y} = \frac{1}{N} \sum_{i=1}^{N} y_i \qquad (3.1)$$

where x_i and y_i are coordinates of vertex i and N is the number of vertices.



VERTEX	X COORDINATE	Y COORDINATE
1	46	56
2	37	68
3	20	20
4	74	20
5	86	70
6	70	84
7	66	40
8	35	32

FIG. 5 REPRESENTATION OF A BLANK AS A POLYGON.

All vertices of the polygon are joined to the centroid $(\bar{x}, \bar{y})$ by straight lines as shown in Figure 5. Area of the polygon is given by,

$$A = \sum_{i=1}^{N} \frac{1}{2} \begin{vmatrix} 1 & 1 & 1 \\ x_i & x_{i+1} & \bar{x} \\ y_i & y_{i+1} & \bar{y} \end{vmatrix} \qquad (3.2)$$

when $i = N$, $i+1 \Longrightarrow 1$.

3.3 Representation of Blanks in Different Orientations (θ) and Positions (D):

Blank (Blank-I) in any orientation θ from its initial orientation ($\theta = 0°$), as shown in Figure 6, is represented in a similar manner as explained in the Section 3.2 by new coordinates of its vertices obtained by transformation of coordinates, using the following expressions.

$$\begin{aligned} x1'_i &= x_i \cos\theta - y_i \sin\theta \\ y1'_i &= y_i \cos\theta + x_i \sin\theta \end{aligned} \qquad i \ \forall\ 1, N \qquad (3.3)$$

$$\begin{aligned} x1_i &= x1'_i - \min(x1'_i) \\ y1_i &= y1'_i - \min(y1'_i) \end{aligned} \qquad i \ \forall\ 1, N \qquad (3.4)$$

where $x1_i$ and $y1_i$ are new coordinates of vertex i. It implies Blank-I is always kept in the first quadrant.

Coordinates of the vertices of Blank-II, at half-turn orientation from that of Blank-I (Figure 6-a) are given by,

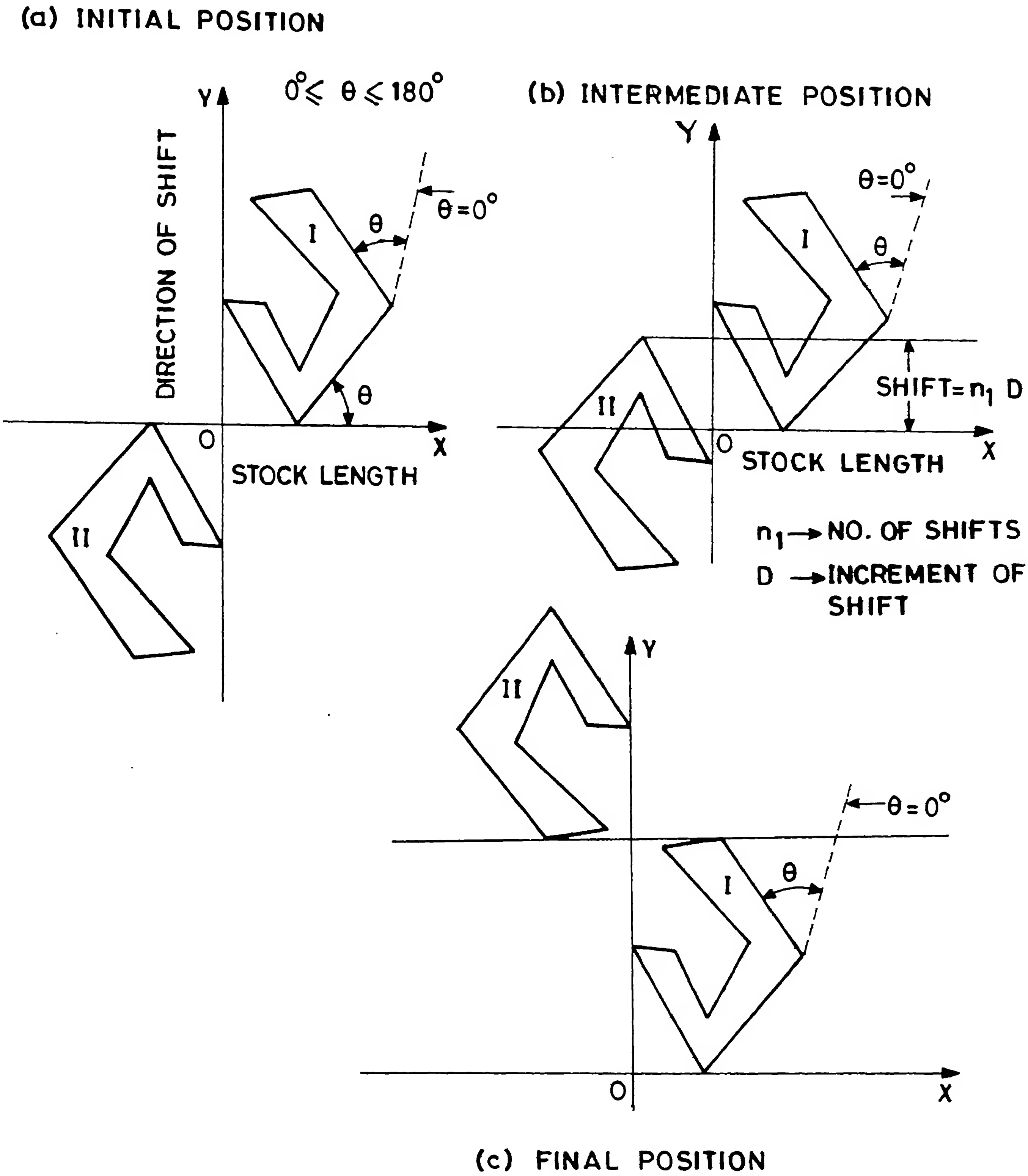


FIG. 6 BLANKS IN DIFFERENT POSITIONS FOR A ORIENTATION.

$$x2_i = -x1_i \qquad i \ \forall \ 1, N \qquad (3.5)$$
$$y2_i = -y1_i$$

Figure 6-a shows initial position of blanks for a given orientation θ. From this initial position, Blank-II is shifted, incrementally, along y-axis (normal to stock length) till it reaches the final position shown in Figure 6-c. Let coordinates of vertices of Blank-II at any intermediate position (as shown in Figure 6-b) be x' and y'. After incremental shift D along y-axis, coordinates of the vertices of Blank-II are given by,

$$x_i'' = x_i' \qquad i \ \forall \ 1, N \qquad (3.6)$$
$$y_i'' = y_i' + D$$

3.4 <u>Calculation of Width W:</u>

Let $(x1_i, y1_i)$ and $(x2_i, y2_i)$ be the coordinates Blank-I and Blank-II respectively and B be bridge width required (Appendix B). Stock width W is given by

$$W = \max(y1_i) - \min(y2_i) + 2B \qquad (3.7)$$

when $\min(y2_i) \leq \min(y1_i)$ (Figure 7-a)

$$\text{or } W = \max(y2_i) + 2B \qquad (3.8)$$

when $\min(y2_i) > \min(y1_i)$ (Figure 7-c).

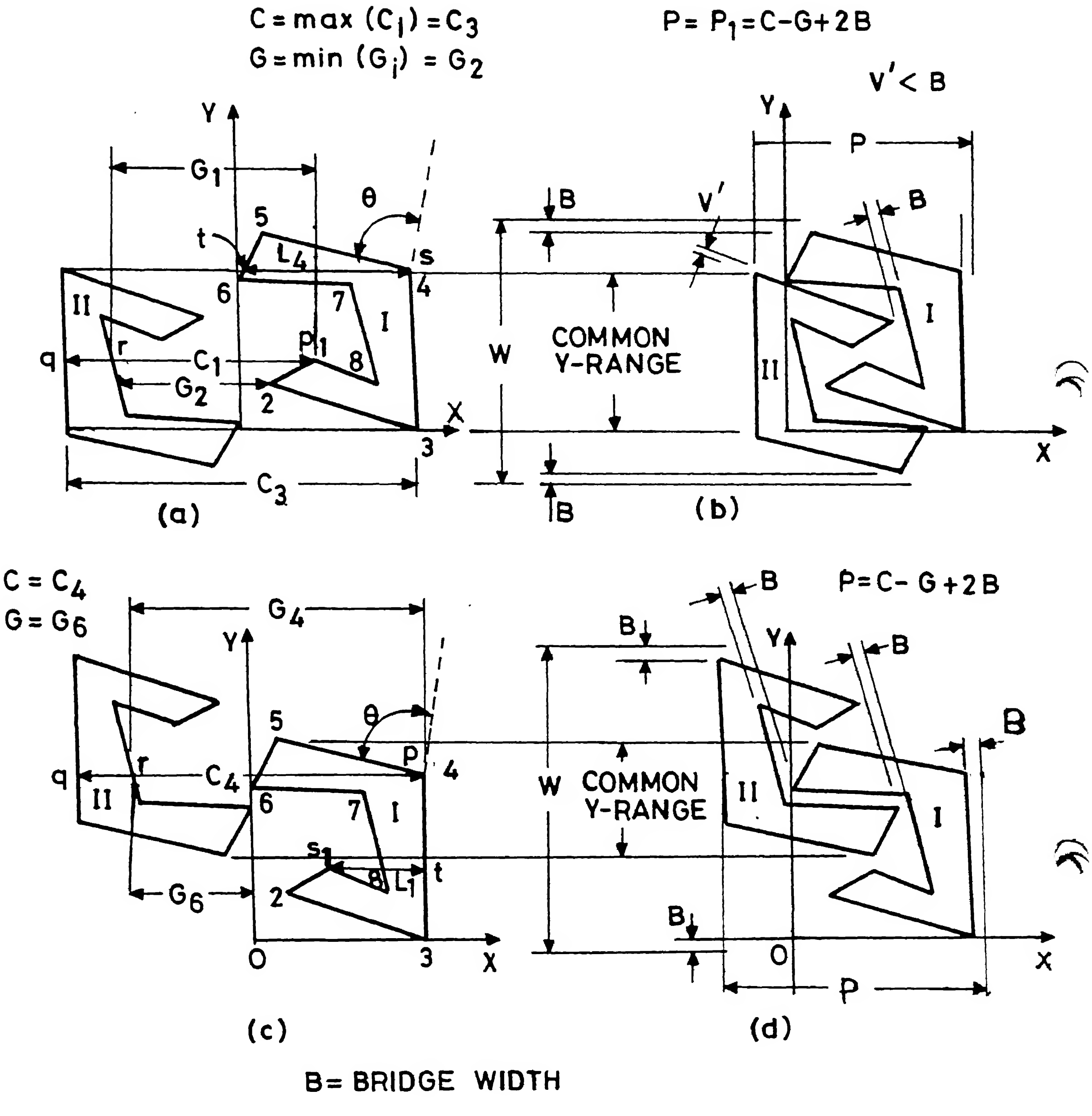


FIG. 7 CALCULATION OF STOCKWIDTH (W) AND PITCH (P) FOR DORHT LAYOUT.

3.5 Calculation of Pitch:

Terminology used is defined below (Figure 7).

Common y-Range is the range of y values common to Blank-I and Blank-II.

Horizontal Length L_i at a vertex i of a blank is the longest of distances from the vertex to the points of intersection that a horizontal drawn from the vertex makes with the sides of the blank (Distance st).

Maximum Horizontal Distance C_i at a vertex i of a blank in the Common y-Range is the longest of distances from the vertex to the points of intersection that a horizontal drawn from the vertex makes with the sides of the other blank (Distance pq).

Minimum Horizontal Distance G_i at a vertex i of a blank in the Common y-Range is the shortest of distances from the vertex to the points of intersection that a horizontal drawn from the vertex makes with the sides of the other blank (Distance pr).

Due to half-turn symmetry, only the vertices of either blank need to be considered to evaluate the above quantities (L_i, C_i and G_i) in order to determine pitch.

Maximum horizontal distance C_i and minimum horizontal distance G_i for a vertex i of Blank-I is given by the following expressions.

When,

$$\left.\begin{array}{ll} & y2_j \le y1_i < y2_{j+1} \\ \text{or} & y2_{j+1} \le y1_i < y2_j \end{array}\right\} \quad \begin{array}{l} j \ \forall\ 1,\ N \ \text{ and if} \\ j = N, \ \ j+1 \Rightarrow 1 \end{array}$$

$$\begin{array}{l} C_i = \max |(x1_i - x_a)| \\ \\ G_i = \min |(x1_i - x_a)| \end{array} \qquad a \ \forall\ 1,\ r \qquad (3.9)$$

where,

r is the number of points of intersection

$$x_a = \frac{y1_i - e_j}{m_j}$$

$$m_j = \frac{y2_{j+1} - y2_j}{x2_{j+1} - x2_j}$$

and $e_j = y2_j - m_j\, x2_j$

To determine pitch P, horizontal length L_i for a vertex i of Blank-I need to be evaluated only if the vertex is outside the common y-Range and is given by the following expressions.

When,

$$\left.\begin{array}{ll} & \min(y2_i) < 0 \quad \text{(Figure 7-a)} \\ & y1_i > \max(y2_i) \\ \text{and} & y1_j \le y1_i < y1_{j+1} \\ \text{or} & y1_{j+1} \le y1_i < y1_j \end{array}\right\} \quad \begin{array}{l} j \ \forall\ i+1,\ N+i-2 \\ \text{if } \ j > N,\ j \Rightarrow j-N \\ \text{if } \ j = N,\ j+1 \Rightarrow 1 \end{array}$$

or

$$\left.\begin{aligned} &\min(y2_i) \geq 0 \quad \text{(Figure 7-c)} \\ &y1_i < \min(y2_i) \\ \text{and } &y1_j \leq y1_i < y1_{j+1} \\ \text{or } &y1_{j+1} \leq y1_i < y1_j \end{aligned}\right\} \begin{aligned} &j \;\forall\; i+1,\ N+i-2 \\ &\text{if } j > N,\ j \Rightarrow j-N \\ &\text{if } j = N,\ j+1 \Rightarrow 1 \end{aligned}$$

$$L_i = \max |(x1_i - x_a)| \qquad a \;\forall\; 1,\ r \tag{3.10}$$

where,

$$x_a = \frac{y1_i - e_i}{m_j}$$

$$m_j = \frac{y1_{j+1} - y1_j}{x1_{j+1} - x1_j}$$

and $$e_j = y1_j - m_j\, x1_j$$

Hence, pitch P is given by,

$$P = \max(P_1, P_2) \tag{3.11}$$

where,

$$P_1 = C - G + 2B$$

$$P_2 = L + B$$

B = Required bridge width (Appendix B)

$$C = \max(C_i) \tag{3.12}$$

$$G = \min(G_i) \tag{3.13}$$

and $$L = \max(L_i) \tag{3.14}$$

3.5.1 Check for Bridge Width in Lateral Direction:

Blank-II is translated close to Blank-I along stock length (x-axis) to get layout of Blanks. New coordinates of the vertices of Blank-II are given by,

$$\left.\begin{aligned} x2'_i &= x2_i + G - B \\ y2'_i &= y2_i \end{aligned}\right. \qquad i \;\forall\; 1, N \tag{3.15}$$

For the position of the blanks, minimum distance between two blanks at some points may be less than the required bridge width as shown in Figure 7-c. To ensure minimum bridge width, the minimum vertical (normal to stock length) distance between the two blanks is determined.

It is necessary to calculate vertical distances from all the vertices of each of the Blanks-I and II to the other blank in order to determine the minimum vertical distance V.

Minimum vertical distance V is given by the following expressions.

When,

$$\left.\begin{aligned} & x2'_j \leq x1_i < x2'_{j+1} \\ \text{or} \quad & x2'_{j+1} \leq x1_i < x2_j \\ & \end{aligned}\right\} \begin{aligned} & i \;\forall\; 1, N \\ & j \;\forall\; 1, N \\ \text{if} \quad & j = N,\; j+1 \Rightarrow 1 \end{aligned}$$

$$V1_i = \min|(y1_i - y_a)| \qquad a \;\forall\; 1, r \tag{3.16}$$

where,

$$y_a = m_j \, x1_i + e_j$$

$$m_j = \frac{y2'_{j+1} - y2'_j}{x2'_{j+1} - x2'_j}$$

and $$e_j = y2'_j - m_j \; x2'_j$$

$$V1 = \min(V1_i) \qquad (3.17)$$

When,

$$\left.\begin{array}{l} x1_j \leq x2'_i < x1_{j+1} \\ \text{or} \quad x1_{j+1} \leq x2'_i < x1_j \end{array}\right\} \quad \begin{array}{l} i \; \forall \; 1, N \\ j \; \forall \; 1, N \\ \text{if} \;\; j = N, \; j+1 \Rightarrow 1 \end{array}$$

$$V2_i = \min |(y2'_i - y_a)| \qquad a \; \forall \; 1, r \qquad (3.18)$$

where,

$$y_a = m_j \; x2'_i + e_j$$

$$m_j = \frac{y1_{j+1} - y1_j}{x1_{j+1} - x1_j}$$

and $$e_j = y1_j - m_j \; x1_j$$

$$V2 = \min(V2_i)$$

$$V = \min(V1, V2)$$

If $V \geq B$, the current position of blanks is acceptable.

3.6 Calculation of Area Utilization:

Percentage area utilization U is given by,

$$U = \frac{2A}{PW} \times 100 \qquad (3.19)$$

Percentage overall area utilization U_o is given by,

$$U_o = \frac{2A}{PW} \times \frac{MW}{S} \times 100 \tag{3.20}$$

where,

$M = \frac{S}{W} - R$ (R - Remainder of $\frac{S}{W}$)

S = Sheet width.

CHAPTER IV

DOUBLE ROW MIRROR IMAGE LAYOUT FOR POLYGON SHAPED BLANKS

4.1 Introduction:

When a part of the boundary of a blank (portion R, Figure 1-d) is gliding mirror image of some other part of the boundary (portion S, Figure 1-d), double row mirror image (DORMI) layout may give higher area utilization than that given by other layouts. In the present chapter, important steps in algorithm for DORMI layout of polygon shaped blanks (PSB) are described. The representation of blank and the method of its area calculation follow steps explained in Section 3.2. Section 4.2 describes representation of blank, and its mirror image in different orientations and positions. Sections 4.3 and 4.4 give method of calculation of stock width and pitch for a given orientation and position of blanks. Subsection 4.4.1 gives layout of blank and mirror image blank. Procedure for calculation of area utilization follows steps explained in Section 3.6.

4.2 Representation of Blanks in Different Orientations (θ) and Positions (k):

Blank (Blank-I), in any orientation θ ($0° \leq \theta \leq 180°$) from its initial position $\theta = 0°$ as shown in Figure 8, is represented by transformed coordinates of its vertices obtained by rotational transformation of coordinates, as given by the following expressions.

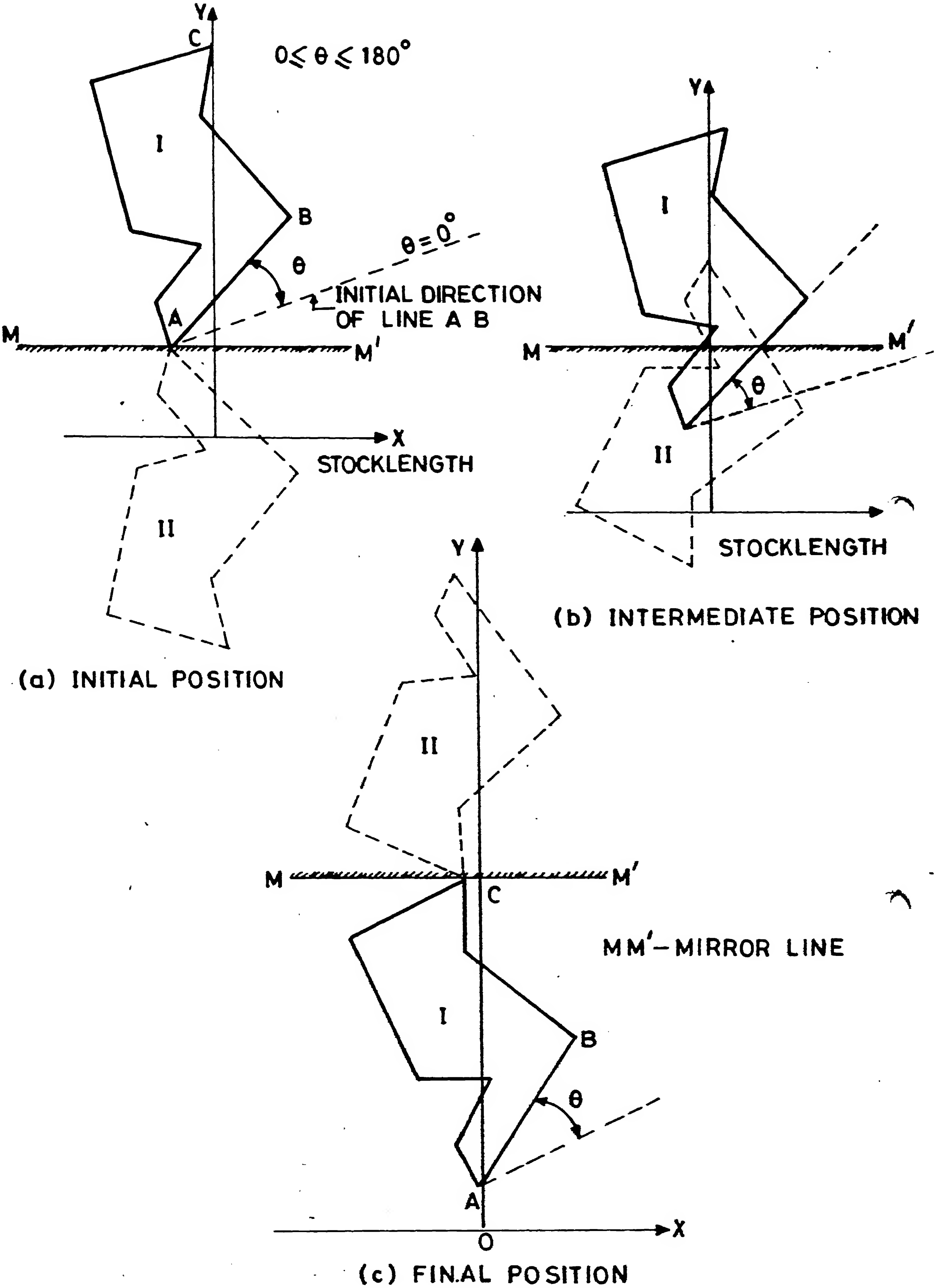


FIG. 8 MIRROR LINE IN DIFFERENT POSITIONS FOR A GIVEN ORIENTATION OF BLANK.

$$x1_i = x_i \cos\theta - y_i \sin\theta \qquad i \forall 1, N \qquad (4.1)$$
$$y1_i = y_i \cos\theta + x_i \sin\theta$$

where (x_i, y_i) and $(x1_i, y1_i)$ are respectively the initial and transformed coordinates of vertex i.

Blank-II, shown in dotted lines in Figure 8, is a conceptual mirror image of Blank-I about a horizontal (i.e., along stock length) mirror line MM'. For each orientation θ, mirror line is initially selected to pass through the bottom most point (say A) of Blank-I (Figure 8-a) and shifted incrementally (Increment D) along y-axis till it passes through the top most point (say C in Figure 8-c). At any position of mirror line MM', say at $y = k$, the coordinates of the vertices of mirror image blank, Blank-II, are given by,

$$x2_i = x1_i \qquad i \forall 1, N \qquad (4.2)$$
$$y2_i = F(y1_i)$$

where F is a function defined by $F(y) = 2k - y$.

4.3 Calculation of Stock Width:

Stock width W is given by,

$$W = \max(y1_i) - F(\max(y1_i)) + 2B \qquad \text{if } k \leq y_m \text{ (Figure 9-a)}$$

$$(4.3)$$

$$= F(\min(y1_i)) - \min(y1_i) + 2B \qquad \text{if } k > y_m \text{ (Figure 9-c)}$$

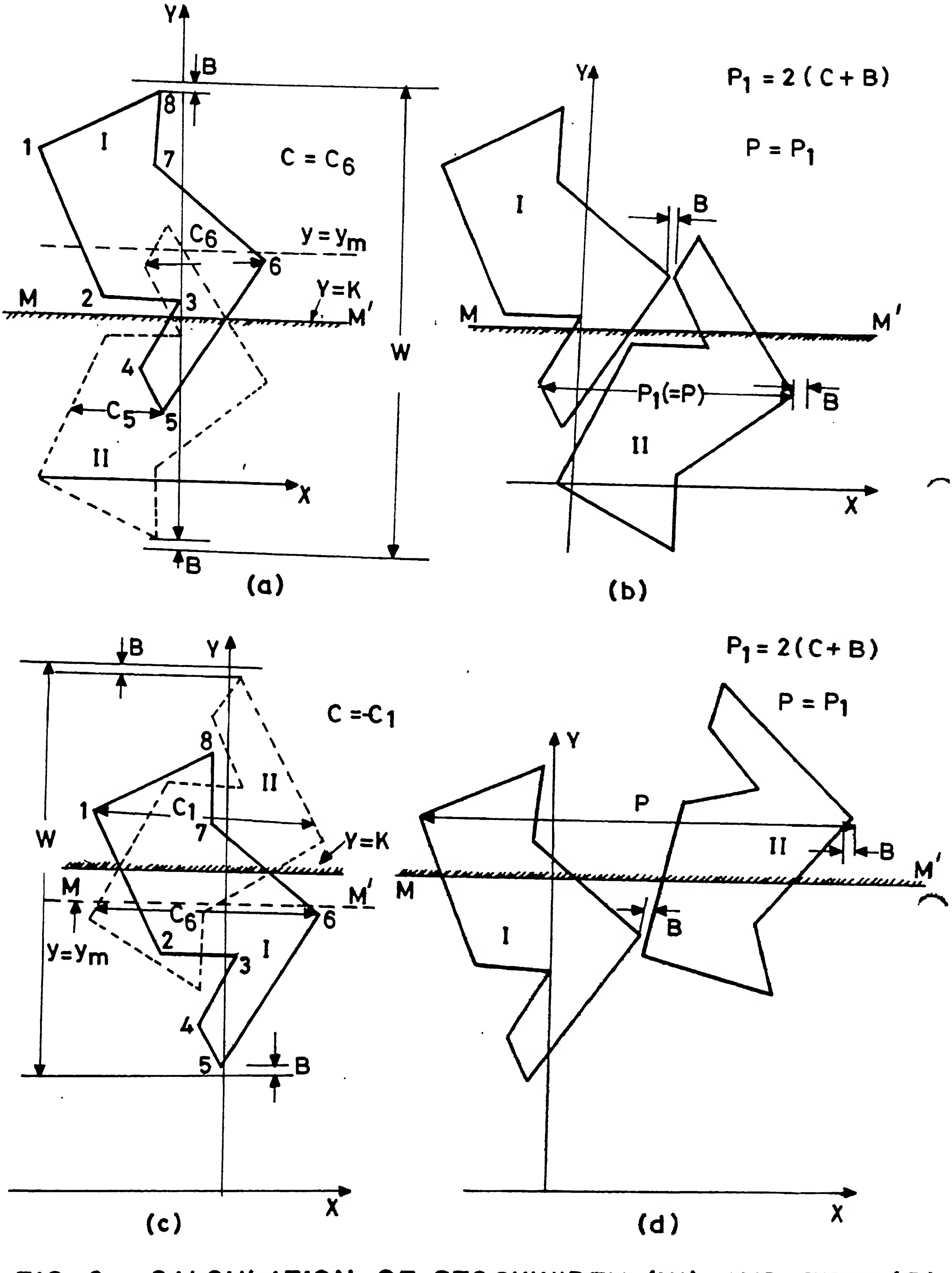


FIG. 9 CALCULATION OF STOCKWIDTH (W) AND PITCH (P) FOR DORMI LAYOUT.

where

$$y_m = \frac{\max(y1_i) + \min(y1_i)}{2} \quad (4.4)$$

4.4 Calculation of Pitch:

Terminology used is described below (Figure 9).

Common y-Range is the range of y values common to Blank-I and conceptual Blank-II.

Horizontal Overlap C_i for DORMI layout is defined in the same way as Maximum Horizontal Distance is defined in Section 3.5 for DORHT layout. Blanks considered for Horizontal Overlaps are mirror images of each other about a mirror line passing through the blanks.

Due to mirror image symmetry, only the vertices of Blank-I need to be considered to evaluate horizontal overlaps and horizontal lengths in order to determine pitch.

Horizontal overlap C_i for a vertex i of Blank-I in the Common y-Range is given by the following expressions.

When,

$$\min(y1_i) \leq y1_i \leq F(\min(y1_i))$$

if $k \leq y_m$ (Figure 9-a)

or

$$F(\max(y1_i)) \leq y1_i \leq \max(y1_i)$$

if $k > y_m$ (Figure 9-c)

$$C_i = \max|(x1_i - x_a)| \qquad a \forall 1, r \quad (4.5)$$

where,

$$x_a = \frac{F(y1_i) - e_j}{m_j} \quad \left. \begin{array}{l} j \,\forall\, 1,\ N \\ y1_j \le F(y1_i) < y1_{j+1} \\ \text{or } y1_{j+1} \le F(y1_i) < y1_j \\ \text{and if } j = N,\ j+1 \Rightarrow 1 \end{array} \right.$$

$$m_j = \frac{y1_{j+1} - y1_j}{x1_{j+1} - x1_j}$$

and $$e_j = y1_j - m_j\, x1_j$$

Horizontal length L_i for a vertex i of Blank-I outside the Common y-Range is given by the following expressions.

When,

$$\left. \begin{array}{l} k \le y_m \\ y1_i > F(\min(y1_i)) \\ y1_j \le y1_i < y1_{j+1} \\ \text{or } y1_{j+1} \le y1_i < y1_j \\ \text{or} \\ k > y_m \\ y1_i < F(\max(y1_i) \\ y1_j \le y1_i < y1_{j+1} \\ \text{or } y1_{j+1} \le y1_i < y1_j \end{array} \right\} \quad \begin{array}{l} j \,\forall\, i+1,\ N+i-2 \\ \text{if } j = N,\ j+1 \Rightarrow 1 \\ \text{if } j \quad N,\ j \Rightarrow j-N \end{array}$$

$$L_i = \max|(x1_i - x_a)| \qquad a \,\forall\, 1,\ r \tag{4.6}$$

where,

$$x_a = \frac{y1_i - e_j}{m_j}$$

$$m_j = \frac{y1_{j+1} - y1_j}{x1_{j+1} - x1_j}$$

and $$e_j = y1_j - m_j \; x1_j$$

Pitch P is determined by the following expressions.

$$C = \max(C_i) \tag{4.7}$$

$$L = \max(L_i) \tag{4.8}$$

$$P_1 = 2(C + B) \tag{4.9}$$

$$P_2 = L + B \tag{4.10}$$

$$P = \max(P_1, P_2) \tag{4.11}$$

4.4.1 Layout of Blank and Image Blank:

For getting layout, either Blank-I or conceptual Blank-II is translated along stock length by a distance equal to maximum horizontal overlap (C) plus bridge width (B) to keep the blanks in non-intersecting positions. If image blank, Blank-II, is translated in the positive x direction (Figure 9-b and Figure 9-d), the coordinates of the vertices of Blank-II in new position are given by,

$$\left.\begin{aligned} x2_i &= x1_i + C + B \\ y2_i &= F(y1_i) \end{aligned}\right\} \quad i \;\forall\; 1, N \tag{4.12}$$

CHAPTER V

INTEGRATION AND IMPLEMENTATION OF ALGORITHMS FOR DIFFERENT STRATEGIES

5.1 Introduction:

In the present chapter, integration and implementation of algorithms for different strategies and cases discussed in Section 2.6 are described. Radhakrishna [4] developed programs in FORTRAN 77 for SIRUO and SIRHT layouts of PSB. He used PLOT-10 IGL graphics package for displaying the layouts. To maintain continuity, the algorithms reported in Chapters III and IV for DORHT and DORMI layouts of PSB are also coded in FORTRAN 77 with PLOT-10 IGL graphics package and implemented on OMEGA 58000 system. The algorithms for SIRUO layout of blanks with arc segments are also implemented.

Integration of algorithms and organization of programs for various strategies are described in Section 5.2. Implementation of programs and discussion of results for some typical blanks are reported in Section 5.3.

5.2 Integration of Algorithms and Organization of Programs:

Algorithms are proposed for all the strategies for layout of PSB discussed in Section 2.6. Since these algorithms essentially solve the same problem of stock layout of PSB, the algorithms are integrated and a single program (hereafter referred to as Program I) is developed. The program is interactive so that the user can judiciously (by examining the

boundary of the blank) select a strategy or strategies in order to arrive at the best solution. Also, the user can deal with any case discussed in Section 2.6 in each strategy, and can improve the accuracy of solution by appropriately responding to the interactive program.

Flow chart of Program I is shown in Figure 10. The program with its subroutines is stored in one source file. The initial input data i.e., sheet thickness, number of vertices and blank coordinates, is stored in an input file. The option of interactive graphic input by defining the PSB on graphics screen using mouse and tablet is also provided. The output data for layout coordinates, stock width, pitch and area utilization is stored in an output file. The graphical output of layouts is displayed on the screen, or can be stored into a file or can be plotted on a plotter.

Subroutines of Program I are briefly described below.

Subroutine GRAINP: It returns the number, and coordinates of vertices of PSB defined on graphics screen.

Subroutine UNIFRM: The initial input data i.e., initial blank coordinates, bridge width, and sheet width and blank area are transferred into the subroutine which gives SIRUO layout.

Subroutine UNIWDH: Current y coordinates and number of vertices are transferred into the subroutine which returns blank width for SIRUO layout.

Subroutine UNIPTH: Current x and y coordinates are transferred into the subroutine which returns pitch for SIRUO layout.

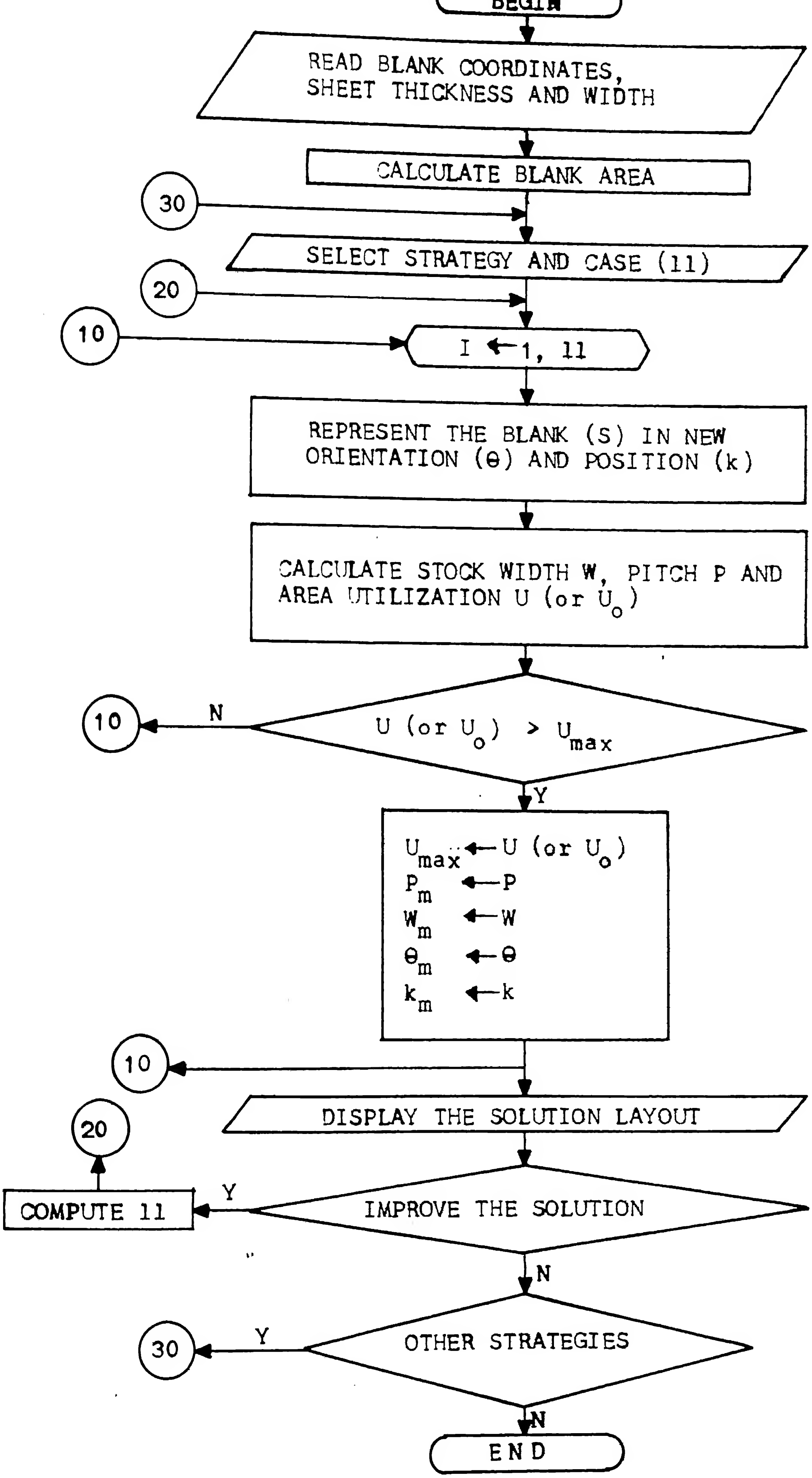


FIG.10 FLOW CHART OF PROGRAM I

Subroutine HORDIS: The x and y coordinates of a chosen side and a vertex of a blank are transferred into the subroutine which returns the horizontal distance between the vertex and the side for SIRUO layout.

Subroutine SNGHFT: The initial input data and blank area are transferred into the subroutine which gives SIRHT layout.

Subroutine MAXMIN: Current x or y coordinates of blank are transferred into the subroutine which returns the maximum and the minimum of x or y values for SIRHT layout.

Subroutine HFTPTH: Current x and y coordinates are transferred into the subroutine which returns pitch for SIRHT layout.

Subroutine HFHRDS: The x and y coordinates of a chosen side of a blank and a vertex of another blank are transferred into the subroutine which returns horizontal distance between the vertex and the side for SIRHT layout.

Subroutine DBLHFT: The initial input data of blank and sheet is transferred into the subroutine which gives DORHT layout.

Subroutine VERDIS: Current x and y coordinates of two blanks are transferred into the subroutine which returns the minimum of vertical distances from the vertices of one blank to the other blank for DORHT layout.

Subroutine SHIFT: The initial input data and current coordinates of Blank-I and Blank-II in their initial position for a orientation are transferred into the subroutine which returns the maximum values of stock width, pitch and area utilization and the corresponding position of the blanks for the orientation for DORHT layout.

Subroutine SNGHRL: Current x and y coordinates of blanks and the limits of Common y-Range are transferred into the subroutine which returns the maximum horizontal length for DORHT layout.

Subroutine SNGHDS: The x and y coordinates of a chosen side and a vertex of a blank are transferred into the subroutine which returns horizontal distance from the vertex to the side for DORHT layout.

Subroutine CMBHDS: Current x and y coordinates of blanks and the limits of Common y-Range are transferred into the subroutine which returns the maximum and the minimum of horizontal distances between the blanks for DORHT layout.

Subroutine SFTHDS: The x and y coordinates of a chosen side of a blank and a vertex of a second blank are transferred into the subroutine which returns horizontal distance between the side and the vertex for DORHT layout.

Subroutine MIRROR: The initial input data of blank and sheet, and blank area are transferred into the subroutine which gives DORMI layout.

Subroutine MSNGHL: Current x and y coordinates of blank and limits of Common y-Range are transferred into the subroutine which returns maximum horizontal length for single blank portion outside the Common y-Range for DORMI layout.

Subroutine MDBLHD: Current x and y coordinates of blanks and limits of Common y-Range are transferred into the subroutine which returns the maximum and the minimum of horizontal distances between the blanks for DORMI layout.

Subroutine LFTRGT: Coordinates of blank and a vertex are transferred into the subroutine which returns the coordinates of farthest point of intersection from the vertex that a horizontal through the vertex makes with the mirror image blank.

Subroutine HORDST: The x and y coordinates of a chosen side and a vertex are transferred into the subroutine which returns the horizontal distance between the vertex and the side for DORMI layout.

5.3 Discussion of Results for Typical Blanks:

5.3.1 Discussion of Results for Polygon Shaped Blanks:

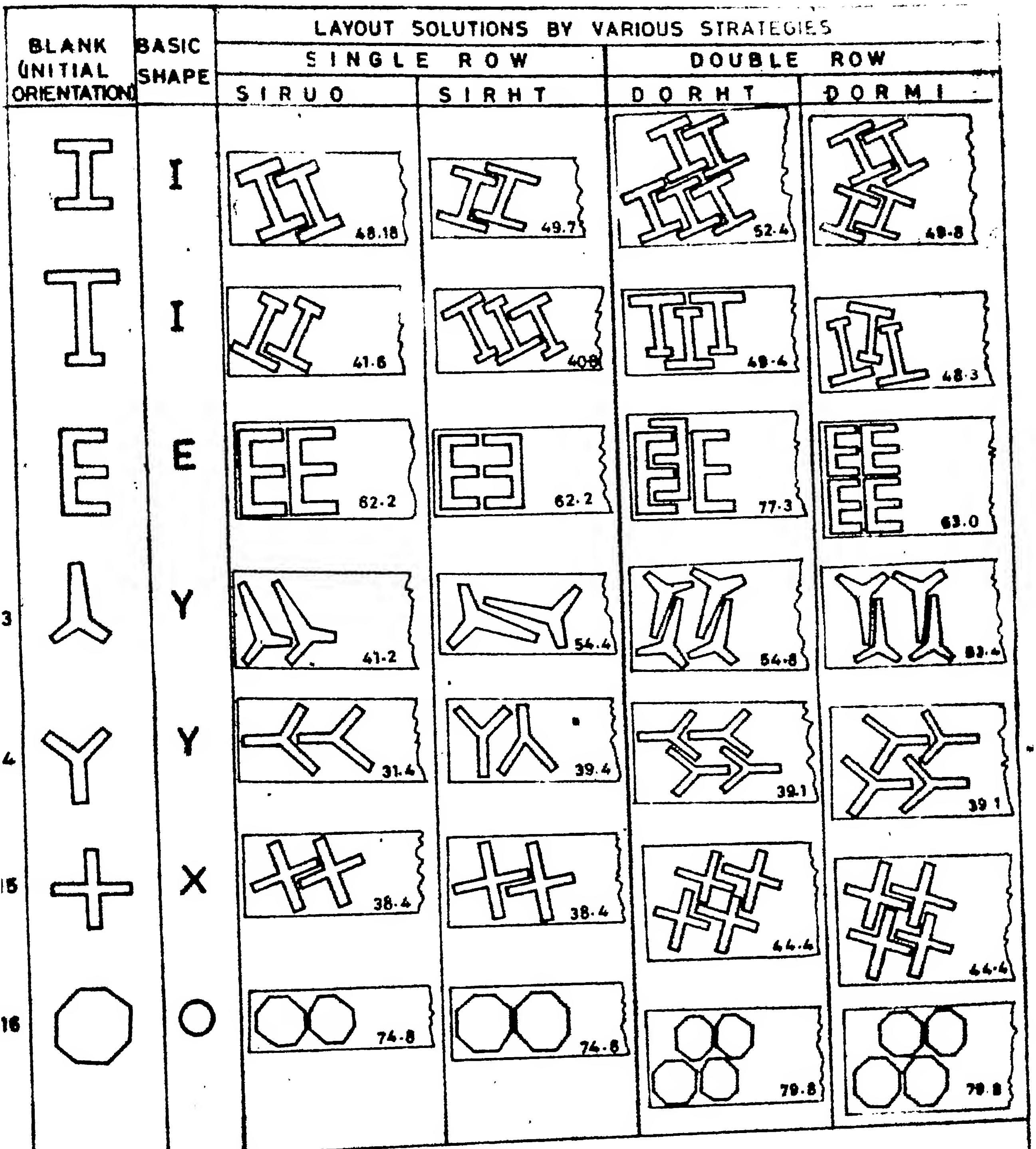
Blanks are grouped under basic shapes such as T, L, O, U, E, I, X and Y. Typical examples for each class are chosen and layout solutions are obtained using various strategies discussed in Section 2.6. The solutions and area utilization for each strategy are shown in Figure 11.

T-Shaped Blanks: For Blank-1, out of the single row layout solutions, SIRHT gives higher utilization of 61.4%. Each of the double row strategies gives identical solution with 66.3% utilization since the blank is symmetrical about a vertical line. The utilization is highest considering all the layout solutions. For Blank-2, out of the single row layout solutions, SIRHT gives higher utilization of 62.4%. But of the double row layout solutions, DORHT gives highest utilization of 66.3% and DORMI gives utilization of 61.5%. For Blank-3 also, DORHT gives highest utilization of 68.0%. For T-shaped blanks tested, out of the single row strategies, SIRHT gives

NO.	BLANK (INITIAL ORIENTATION)	BASIC SHAPE	LAYOUT SOLUTIONS BY VARIOUS STRATEGIES: SINGLE ROW		DOUBLE ROW	
			SIRUO	SIRHT	DORHT	DORMI
1		T	51.6	61.4	66.3	66.3
2		T	58.0	62.4	66.3	61.5
3		T	55.0	60.[illegible]	68.0	61.1
4		L	54.0	43.2	61.4	61.4
5		L	72.7	75.1	75.4	76.2
6		L	79.8	81.6	81.6	82.7
7		L	48.9	61.5	69.5	69.5
8		U	59.1	53.1	68.9	61.2
9		U	51.7	53.51	59.9	67.0

SIRUO → SINGLE ROW UNIFORM ORIENTATION
SIRHT → SINGLE ROW HALF-TURN
DORHT → DOUBLE ROW HALF-TURN
DORMI → DOUBLE ROW MIRROR IMAGE

Contd.



SIRUO → SINGLE ROW UNIFORM ORIENTATION
SIRHT → SINGLE ROW HALF-TURN
DORHT → DOUBLE ROW HALF-TURN
DORMI → DOUBLE ROW MIRROR IMAGE

FIG.11. VARIOUS BLANKS AND THEIR LAYOUT SOLUTIONS
(BRIDGE WIDTH IS 1.5 mm)

higher utilization and out of the double row strategies, DORHT gives highest utilization.

L-Shaped Blanks: For Blank-4, out of the single row layout solutions, SIRUO gives higher utilization of 54.0%. For Blank-4 and Blank-7 which have limbs of approximately equal dimensions, each of the double row layout solutions gives equal area utilization of 61.4% for Blank-4 and 69.5% for Blank-7. The utilization is highest for each of the blanks considering all the solutions. For Blank-5 and Blank-6, which have limbs of unequal dimensions, utilization given by DORMI strategy is highest and is slightly higher than that given by DORHT strategy. Hence, for considered L-shapes with limbs having equal dimensions, utilizations given by the double row strategies are equal and highest considering all the solutions. When limbs are of unequal dimensions, the highest utilization, given by DORMI strategy, is slightly higher than that given by DORHT strategy. Also, double row layout solutions give higher utilization than those given by single row layouts.

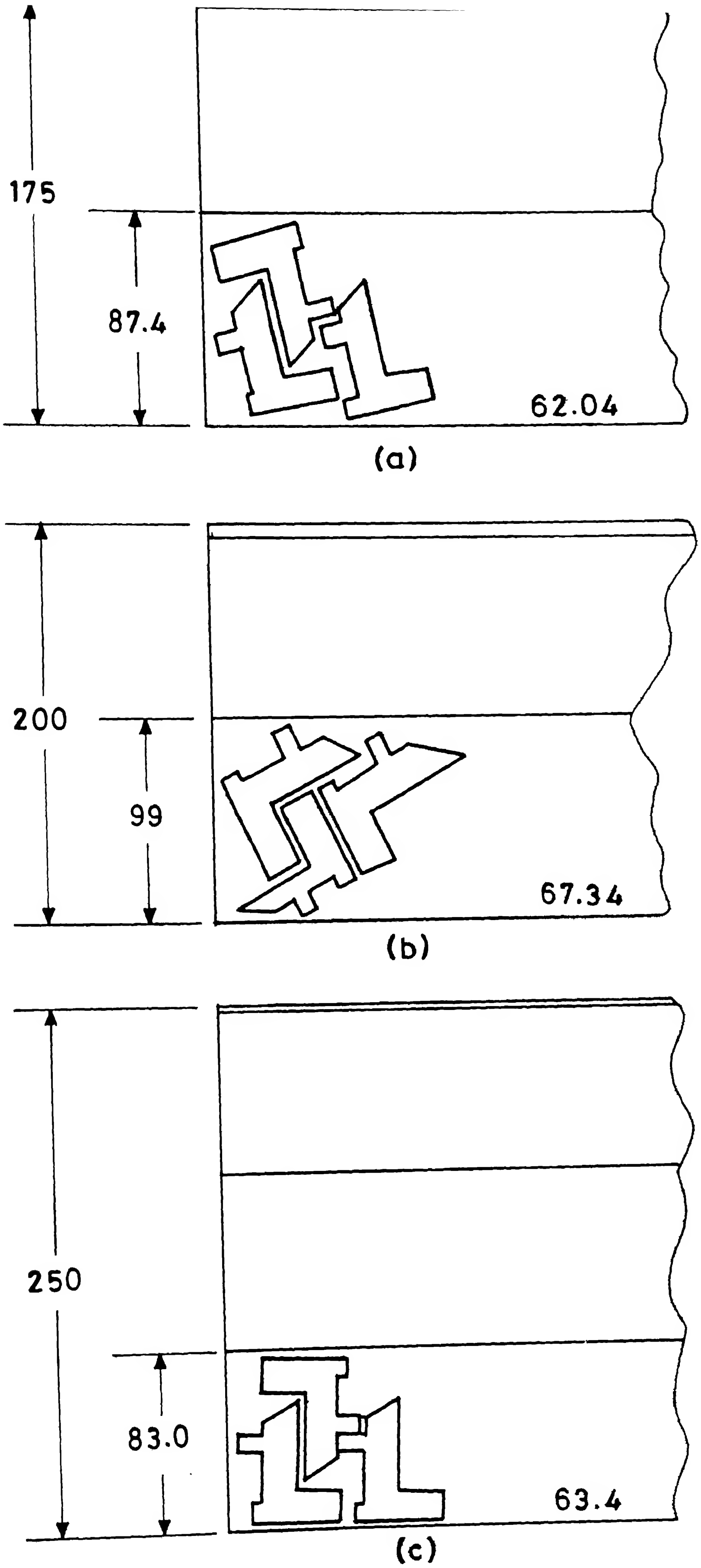
Out of the single row solutions, SIRHT gives higher utilization for all the blanks shown in Figure 11 except for Blank-4. Out of the double row layout solutions, DORHT gives higher utilization except for L-shaped blanks (Blank-5 and Blank-6). In general, half-turn — SIRHT and DORHT — layout solutions give higher utilization. Also, double row layout solutions give higher utilization than those given by single row layouts excepting few cases as in Blank-2, Blank-13 and Blank-14 where the difference in utilization is nominal.

5.3.2 Effect of Sheet Width on Layout Solution:

The effect of sheet width constraint on layout (say DORHT layout) solution for a blank is illustrated by the example shown in Figure 12. Area utilization without sheet width constraint is 68.0% for DORHT layout solution of the blank (Blank-3 in Figure 11). The layout solutions with sheet widths 175 mm, 200 mm and 250 mm are shown in Figure 12. The layout solutions and corresponding area utilizations are different for each sheet width. The layout solution for sheet width of 200 mm corresponds to that obtained without sheet width constraint and consequently the area utilization is high for the sheet width is approximately two times stock width (99 mm).

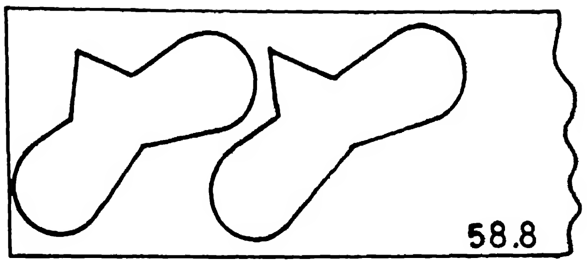
5.3.3 Discussion of Results for Blanks with Arc Segments:

The algorithms proposed by Radhakrishna [4] for SIRUO layout of blanks with arc segments is corrected (Appendix A) and implemented. Figure 13 shows some blanks and their SIRUO layout solutions. Area utilization is given on each layout. For blank shown in Figure 13-c, the area utilization of 86.53% is high since the concave arc segment of the blank perfectly fits into the convex arc segment of next blank.



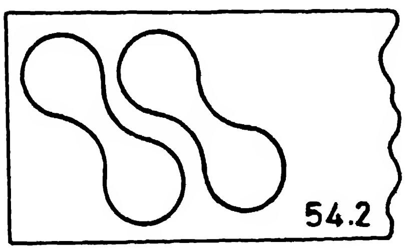
ALL DIMENSIONS ARE IN MM

FIG.12 EFFECT OF SHEET WIDTH CONSTRAINT ON D O R H LAYOUT SOLUTION [BRIDGE WIDTH = 2 M M].



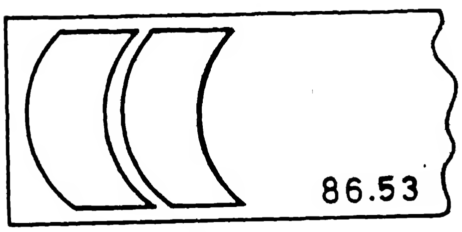
(a)

[BRIDGE WIDTH = 1.5 mm]



(b)

[BRIDGE WIDTH = 3.5 mm]



(c)

[BRIDGE WIDTH = 2.0 mm]

FIG.13 S I R U O LAYOUT SOLUTIONS FOR BLANKS WITH ARC SEGMENTS.

CHAPTER VI

CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

6.1 Conclusions:

Algorithms for various strategies of layout of polygon shaped blanks (PSB) are tested. In general, half-turn — SIRHT and DORHT — layouts give better solutions with higher area utilization. Also, double row layout solutions give better utilization than single row layout solutions. It can be further concluded that DORHT layout solution gives highest utilization in general.

The algorithm for SIRUO layout of blanks with arc segments is also tested.

The developed programs enable the designer to select an appropriate layout from the solutions by various strategies. Also, these programs help in product design where shape and size of blank can be modified within functional limits to improve area utilization.

The programs along with input and output formats can be suitably changed to meet specific requirements.

Various strategies can be applied for blanks with curved segments by approximating the blank as a polygon with sufficient number of sides to represent closely its original shape.

Computer-aided stock layout for blanking is economical for medium size production of moderate variety of blanks, as any CAD/CAM system caters to. This can be implemented as a

liasion activity in the integrated manufacture of sheet metal components using CAD/CAM systems.

6.2 Suggestions for Further Work:

In the present work, bridge width is taken as one and a half times sheet thickness and is provided in the direction of, and normal to, stock length. To get an acceptable layout, the algorithms can be further refined to provide required bridge width considering the direction of minimum distance between closest segments of adjacent blanks. Practical considerations governing bridge width such as blank size, sheet material etc. can also be incorporated.

Algorithms for SIRHT, DORHT and DORMI strategies of layout of blanks with arc segments can also be developed.

For various strategies of layouts, the algorithms for design of dies can be developed and integrated with the algorithms for layouts. Comprehensive cost evaluation can be performed considering savings in material and escalation in die cost due to increase in complexity of die.

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APPENDIX A

CORRECTIONS IN ALGORITHMS FOR SINGLE ROW LAYOUTS

This appendix gives corrections to be made in the algorithms for single row layouts reported in Radhakrishna's [4] thesis. Section numbers, equations numbers, figure numbers and page numbers correspond to the numbers given in his report.

3.21 Determination of Width (p. 22):

$$H = \max(y_i') - \min(y_i') \qquad i \;\forall\; 1, N \qquad (3.4)$$

3.22 Determination of Pitch for Single Row Layout (p. 23):

The horizontal lengths HL_i are determined from the following expressions.

When,

$$y_j'' \leq y_i'' < y_{j+1}'' \qquad i \;\forall\; 1, N$$

$$\text{or} \quad y_{j+1}'' \leq y_i'' < y_j'' \qquad j \;\forall\; i+1, N+i-2$$

$$\text{if} \quad j = N, \; j+1 \Rightarrow 1$$

$$\text{and if} \quad j > N, \; j \Rightarrow j-N$$

$$(HL)_i = \max|(x_i'' - x_p)| \qquad p \;\forall\; 1, K \qquad (3.5)$$

where,

$$x_p = \frac{y_i'' - e_j}{m_j}$$

$$K = \text{number of points of intersection}$$

$$e_j = y_j'' - m_j\, x_j'' \quad \text{and} \quad m_j = \frac{y_{j+1}'' - y_j''}{x_{j+1}'' - x_j''}$$

3.23 Determination of Pitch for a Pairwise Layout (p. 25):

The coordinates of the pair are given by,

$$x2_i = -x1_i \qquad\qquad i \forall 1, N \quad (3.7b)$$
$$y2_i = -y1_i + \max(y1_i') - \min(y1_i')$$

The minimum and maximum horizontal distance between the component and its pair HL_{min}, HL_{max} are calculated by the following expressions.

When,

$$y2_j \leq y1_i < y2_{j+1} \qquad i \forall 1, N$$
$$j \forall 1, N$$
$$\text{or} \quad y2_{j+1} \leq y1_i < y2_j \qquad \text{and if } j = N, j+1 \Rightarrow 1$$

$$(HL1)_i = \max|(x1_i - x_p)| \qquad p \forall 1, K \qquad (3.8)$$
$$(HL2)_i = \min|(x1_i - x_p)|$$

4.11 Component Representation (p. 28):

page 31:

The start angle θ_1 and end angle θ_2 representing the span of the arc segment are illustrated in Figure 10. Angles θ_1 and θ_2 are so defined that θ_2 is always greater than θ_1 for counter clockwise arcs and θ_1 is always greater than θ_2 for clockwise arcs.

For clockwise arc segments,

i.e. when $I_c = 0$

$$\text{if} \quad (\theta_2')_i > (\theta')_i \qquad i \forall 1, N$$

$$(\theta_1)_i = (\theta_1')_i + 360° \qquad (4.4a)$$

$$(\theta_2)_i = (\theta_2')_i$$

For counter clockwise arc segments, i.e. when $I_c = 1$

$$\text{if} \quad (\theta_2')_i < (\theta_1')_i \qquad i \;\forall\; 1, N$$

$$(\theta_2)_i = (\theta_2')_i + 360° \qquad (4.4b)$$

$$(\theta_1)_i = (\theta_1')_i$$

4.12 Area Calculation (p. 33):

page 35:

$$A''' = \sum_{i=1}^{N} \left[0.5(\theta_2 - \theta_1)r^2 - \frac{1}{2} \quad \begin{matrix} 1 & 1 & 1 \\ x^1 & x^2 & x^c \\ y^1 & y^2 & y^c \end{matrix} \right]_i \qquad (4.8)$$

4.22 Pitch Calculation (p. 37):

page 39:

$$y_{max} = y_j^c \pm \frac{r_j}{\sqrt{1 + m_i^2}} \qquad (4.13)$$

page 41:

$$x_j^{incpt} = x_j^c \pm (r_j^2 - (y_{max} - y_j^c)^2)^{1/2}$$

page 44:

$$y_{max} = \frac{r_i y_j^c + r_j y_i^c}{r_i + r_j} \qquad \text{when} \quad r_i \neq r_j \qquad (4.17)$$

$$\text{and when} \quad r_i = r_j$$

APPENDIX B

BRIDGE WIDTH ALLOWANCES

This appendix gives bridge width allowances between blank and sheet-stock edge and between blanks [8].

Table-I. Bridge Width Between Blank and Sheet-Stock Edge

(in millimetres)

Blank width	Aluminium stock upto 0.5 mm thick	Aluminium over 0.5 mm thick, brass, copper, steel
upto 40 mm	2.5	1.5
40 to 75 mm	3.0	2.5
75 to 150 mm	5.0	3.0
150 mm and over	6.0	5.0

Table-II. Bridge Width Between Blanks

Stock thickness (mm)	0.3	0.5	0.8	1.0	1.25	1.52	1.8	2.0	2.25	2.5	3.0
Bridge width (mm)	0.5	0.6	0.8	0.9	1.0	1.12	1.27	1.4	1.52	1.65	1.8

APPENDIX C

DOCUMENTATION OF THE PROGRAM FOR IMPLEMENTATION ON OMEGA 88000 SYSTEM

The program is kept in different source files namely: (1) blanks3.f, (2) junk.f, (3) simple.f, (4) subrt1.f, (5) pair.f, (6) subrt2.f, (7) pair2.f, (8) shift2.f, (9) switch.f, (10) verdis.f, (11) mirror1.f, (12) subhgt1.f and (13) exphgt1.f. All the files are compiled together to prepare an executable code. At present, there is an executable code named "total" in the directory, which is prepared in the same manner as said above.

Before running the code, it is to be ensured that there is a file named "mod.inp" in the directory and WMS is running. "mod.inp" is input file.

<u>Stages of Interaction:</u>

(I) First the program asks-

DO YOU WANT TO GIVE GRAPHIC INPUT ("y"/"n")

(i) If yes:

(a) Type in -

'y' CR

(b) Next, the Program asks -

GIVE SHEET THICKNESS

Type in the thickness in mm. of sheet.

(c) The Program asks in the graphics environment -

Give no. of vertices

Type in the number (integer) of vertices of PSS for which layout is to be obtained.

(d) The program gives an alarm to locate a point (vertex). Activate the OMEGA PLOT window and place the crosswire cursor at a required point on the graphic screen.using mouse and tablet. Press any key to digitize the point. Again, the locate routine gives an alarm to locate another point (by vertex) and the same procedure is followed. The program draws straight lines as the points are located and once all the given number of vertices are located, a closed polygon is defined.

(2) If no: (a) Type in -

'n' CR

The program reads the input data, already stored in the input file "red.inp". In the input file "red.inp", the first line should give the sheet thickness (in mm). The second line should give the number of vertices of PSS. Third line should give the x-coordinates of all the vertices about any orthogonal xy-reference frame. Fourth line should give the y-coordinates of all the vertices.

II. The Programs asks in the graphics environment -

Give stock width:

Activate the window in which the Program is being run. Type in sheet width in mm., if you want to specify the standard width of the sheet. Otherwise, type any number less than 1, if there is no sheet width constraint.

III. The program asks -

FOR SINGLE ROW UNIFORM ORIENTATION LAYOUT TYPE 1

FOR SINGLE ROW HALF-TURNLAYOUT TYPE 2

FOR DOUBLE ROW HALF-TURN LAYOUT TYPE 3

FOR DOUBLE ROW MIRROR IMAGE LAYOUT TYPE 4

TO STOP TYPE 5

Type in appropriate integer to obtain the corresponding layout.

IV. If the graphics screen is displayed, but the layout is not displayed, then key in any number to get the graphic display of layout solution. The orientation of the blank in the layout from the initial position and utilization of the layout can be read from the window in which the program is being run.

V. Type in any number to come out of the graphics environment.

VI. Again the same message as given in step III is displayed. Any other layout solution can be obtained by keying in appropriate integer or the program can be stopped by keying in integer '5' as given in the message.